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Article

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Abstract

A simple model of bank behaviour is shown to have implications for solvency regulation of the *Basel* type. The investment division seeks to maximize *RORAC*, with higher solvency *S* lowering the cost of refinancing but tying costly capital. In period 1, exogenous changes in expected returns $d\bar{\mu}$ and in volatility $d\bar{\sigma}$ occur, causing optimal adjustments $dS^*/d\bar{\mu}$ and $dS^*/d\bar{\sigma}$ in period 2. In period 3, the actual adjustment dS^* creates an endogenous trade-off with slope $d\hat{\mu}/d\hat{\sigma}$. *Basel*-type regulation modifies this slope, inducing senior management to opt for a higher value of σ in several situations. Solvency regulation can thus run counter its stated objective.

Keywords

Regulation, banks, solvency, *Basel I*, *Basel II*, *Basel III*

Risk-adjusted return on (risk-adjusted) capital (RAROC) is the dominant benchmark for assessing the performance and governance of banks' investment divisions. For them, a higher solvency level has the benefit of lowering the cost of refinancing; on the other hand, it ties costly capital. At the same time, public regulators are concerned about solvency to ensure the continuity of a bank's operations. This article deals with the conflict between the optimization of solvency by the bank itself and exogenously imposed solvency levels, taking *Basel I* and *Basel II* as the example. It depicts a bank in the process of its sequential

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decision-making. In the first period, exogenous shocks on expected returns and volatility impinge on the bank's investment division (the division henceforth). A typical cause could be investments made in the previous period that turn out to have a lower rate of return or a higher volatility than expected. In the second period, the Division adjusts its solvency level in response to these shocks in ways predicted by maximization of RAROC and comparative-static analysis. In the third period, the Division proposes to senior management to rebalance the bank's asset position in response to the changed solvency level through endogenous adjustments by opting for new values for expected returns and volatility, respectively. These changes define the slope of an internal efficiency frontier on which senior management chooses the optimum, taking into account its degree of risk aversion.

This efficiency frontier is modified by solvency regulation such as *Basel I* and *II*. It will be argued that *Basel I* neglects the fact that both the cost of refinancing and its relationship with solvency depend on changes in expected returns and volatility that are exogenous to the bank of the type occurring in period 1. As to *Basel II*, it addresses solvency directly but still fails to take into account that for a bank that initially just met this standard, the amount of risk capital needed to improve solvency changes when the market environment changes in terms of expected returns und volatility. It will be shown that both *Basel I* and *II* modify the slope of the efficiency frontier as perceived by regulated banks. While one might expect that these regulations reduce the slope of the frontier (thus inducing senior management to opt for lower expected returns and lower volatility), it turns out that the opposite can well be the case. Indeed, through their neglect of parameters of importance to banks themselves, both *Basel I* and *II* may have the unexpected consequence of causing at least some banks in several constellations to opt for a higher volatility in the rate of return on their assets than without it, causing regulation to miss its target. This risk is likely to increase also in the case of impending *Basel III* regulation, without however attaining the importance in the case of *Basel I*. Both the International Monetary Fund and the European Bank are engaged in stress testing of banks, where exogenous shocks of the type analyzed in this article are simulated. The need for such tests can be interpreted as being the consequence of current *Basel*-type regulations inducing excessive risk-taking through their neglect of these shocks.

This article is structured as follows. The section 'Literature Review' contains a review of the pertinent literature to conclude that solvency regulation indeed may serve to avoid negative externalities. In the section 'Optimal Solvency in a Model of a Bank's Investment Division', a higher level of *Basel I* is found to have two effects on a bank's investment division aiming to maximize RAROC. On the one hand, it serves to lower its cost of refinancing; on the other, it ties capital that would have other, more productive uses. This optimum is disturbed by exogenous shocks in terms of expected returns and volatility in the market environment (see period 1 of Figure 1). In period 2, the Division adjusts the bank's solvency level to these shocks. These adjustments are derived in the section 'Adjustment of Solvency to Exogenous Shocks' using comparative static analysis. However, there can be only one adjustment of solvency, which in period 3 acts similar to an

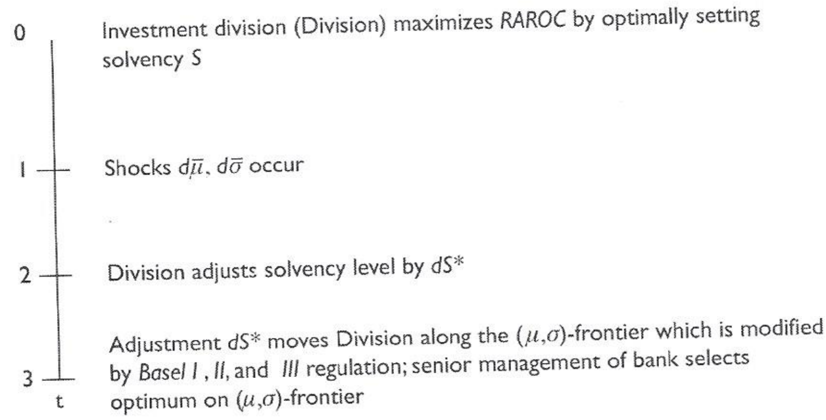


Figure 1. Timeline of the Model

exogenous change causing the bank to move along an endogenous efficiency frontier. By performing comparative statics 'in reverse', the slope of this frontier is derived in the section 'Determination of the Endogenous Efficiency Frontier'. Senior management is presented with this trade-off and makes its choice taking account of its degree of risk aversion. The regulations imposed by *Basel I, II* and *III* are introduced as parameter restrictions in the section 'Effects of Solvency Regulation on the Efficiency Frontier' to show how the slope of this efficiency frontier is modified, inducing senior management of regulated banks to opt for a higher volatility than absent this regulation in a number of situations. A summary and conclusions follow in the section 'Summary and Conclusion'.

Literature Review

The solvency regulation of banks has traditionally been justified by the external costs of insolvency, especially in the guise of a bank run (Diamond and Dybvig, 1983). This view was challenged by the proponents of the Capital Asset Pricing Model, who emphasized that for well-diversified investors, the solvency of a bank does not constitute a reasonable objective. They are concerned with expected profitability, adjusted for the degree to which the bank's profitability systematically varies with the capital market (the Beta of the Capital Asset Pricing Model). By way of contrast, for little-diversified investors (among them, ordinary consumers holding deposits with the bank), the bank's overall risk is relevant, which importantly includes the risk of insolvency (Goldberg and Hudgins, 1996, 2002; Jordan, 2000; Park and Peristiani, 1998). Option pricing theory shows that due to their limited liability, shareholders of the bank in fact have a put option that is written by the other stakeholders (notably creditors) of the bank (Jensen and Meckling, 1976; Merton, 1974, 1977).

When a solvency risk materializes, internal and external costs need to be distinguished. Internal costs are borne by the bank's shareholders, who see the value of their shares drop to zero unless the bank is in business again. However, in view of the loss of reputation, this re-entry would meet with high barriers to entry (Smith and Stulz, 1985: 395–396; Stulz, 1996: 9–12). In addition, insolvency has external costs (i.e., costs not borne by the insolvent bank). First, the insolvency may trigger a bank run (Bauer and Ryser, 2004; Diamond and Dybvig, 1983; Jacklin and Bhattacharya, 1988). Depositors who are late to withdraw their funds stand to lose part of their assets. Some of these depositors may be banks themselves; therefore, the insolvent bank may drive other financial institutions into bankruptcy, causing substantial external costs (Furfine, 2003; Lang and Stulz, 1992). Second, investors in the capital market at large often are affected as well. A bank that becomes insolvent causes owners and creditors of banks in general to re-evaluate the estimated risk of insolvency. In response to the revised estimate, they demand a higher rate of interest from their banks, driving up the cost of refinancing. There is a substantial body of empirical research substantiating this claim (Covitz et al., 2004; Flannery and Sorescu, 1996; Park and Peristiani, 1998).

This research suggests that a solvency level that is deemed optimal by the individual bank is too low from a societal perspective because insolvency causes substantial external costs. However, it may be worthwhile to emphasize that this conclusion does not suffice to justify public regulation to ensure solvency. One would have to first examine whether the expected benefit of the intervention exceed its expected cost. An important component of this cost is caused by behavioural adjustments that are not intended. The present contribution belongs to this tradition of research, which dates back at least to Koehn and Santomero (1980). Characterizing a bank by its utility function and assuming it to optimize a portfolio containing both assets and liabilities, they find that imposing a simple equity-to-assets ratio constraint is ineffective on average. Relatively safe banks become safer, while risky ones increase their risk position to make up for decreased leverage. In Kim and Santomero (1988), emphasis is on the choice of appropriate risk weights in the determination of what has since become 'risk-adjusted capital'. Here, the cost of regulation derives from non-optimal risk weights.

In Rochet (1992), banks choose their asset portfolio taking into account limited liability, which may cause them to become risk-lovers. This makes imposing minimum capital requirements necessary to prevent them from choosing very inefficient portfolios. However, the effectiveness of this regulation is not guaranteed at all. John et al. (2000) show that U.S. capital-based regulation introduced in 1991 may fail to prevent bank managers from shifting risk to outside financiers unless features of their compensation plans are taken into account along with the opportunity set of asset investments. More recently, Repullo (2004) explicitly has dealt with *Basel II* in the context of an imperfectly competitive market. He derives conditions for two Nash equilibria to obtain, one in which banks invest in riskless and another where they invest risky assets. While capital requirements on risky assets do enlarge the parameter space of the 'prudent' equilibrium, depositors bear the burden of regulation in the guise of lower interest rates. That is also the reason why in Repullo (2004) capital requirements are in general effective in preventing excessive risk-taking by banks. Furthermore, it is shown that *Basel II* permits a reduction in the overall amount of capital required by regulation compared to

Basel I. However, pointing to bank-specific problems of governance, Mülbert (2009) argues that prudential regulation of the *Basel I* and *Basel II* type may even induce rather than prevent banking crises.

The present contribution differs from the earlier literature in two ways. First, it clearly distinguishes between the earlier *Basel I* and the more refined *Basel II* regulation, showing that the more recent variant may have unintended consequences only for a subset of banks rather than all of them. However, *Basel III* is found to likely increase this subset again. In this respect, this work elaborates on and refines the contributions by Kim and Santomero (1988) as well as Rochet (1992). The second distinguishing feature of this article is its emphasis on dynamics in the following way. Whereas earlier contributions analyzed optima or [in the case of Repullo (2004)] equilibria, here the bank's path of adjustment from one optimum to the next is analyzed. Adjustment to exogenous shocks will be shown to be conditioned by solvency regulation of the *Basel I* to *III* type. In return, welfare implications will not be spelled out; rather, the fact that banks may be induced to act against the stated intentions of the regulator will be highlighted.

Optimal Solvency in a Model of a Bank's Investment Division

Let a bank's investment division (the Division henceforth) maximize the expected rate of return on risk-adjusted capital (RAROC, to be defined below) through its choice of solvency S. By assumption, senior management mandates the division to act in a risk-neutral manner. This can be justified by noting that allowing risk aversion to affect decisions taken by employees of the Division would result in inconsistencies. Employee A (who is strongly risk averse) might turn down a client seeking to obtain funding for a project while employee B (who has more of a risk appetite) of the same bank would accept it. Senior management needs to avoid such inconsistencies. Therefore, the expectation operator is dropped as long as the Division is being analyzed; risk aversion will enter in period 3 when the bank's senior management selects its preferred position on the (μ,σ)-efficiency frontier generated by the Division (assuming that it applies (μ,σ)-analysis as an approximation in the presence of skewness and kurtosis of returns). A higher level of solvency S enables the bank (and hence the division) to obtain funds at a lower rate of interest paid on deposits r_D.

While there is no need to define *Basel I* in a formal way, it may be thought in terms of the likelihood of a shortfall (Leibowitz et al., 1992) or in terms of value-at-risk (VaR) or expected value-at-risk (EVaR) concepts [however, see Artzner et al. (1999) for a critique]. Whenever VaR or EVaR increases, the solvency level can be said to decrease. Also note that economics is replete with latent (i.e., not directly observed) variables ever since Keynes' (1936) 'state of confidence', Friedman's (1957) 'permanent income', and Barro's (1977) 'unanticipated money growth'. For concreteness, the VaR criterion adopted by *Basel II* is used here. However, whatever the definition employed, the crucial fact is that the level of solvency constitutes a decision variable for the bank. For, the bank is confronted with refinancing cost according to the rate of interest it has to pay on its deposits r_D,

$$r_D = r_D(\cdot, S), \text{ with } \frac{\partial}{\partial S} r_D(\cdot, S) < 0 \text{ and } \frac{\partial^2}{\partial S^2} r_D(\cdot, S) > 0; \tag{1}$$

the arguments other than S are discussed in the third section. The amount of risk-adjusted capital $C > 0$ increases with the solvency level S aimed at by the bank,

$$C = C(\cdot, S) \text{ with}$$

$$\frac{\partial}{\partial S} C(\cdot, S) > 0, \ \frac{\partial^2 C}{\partial S^2} > 0. \tag{2}$$

Note that Eqs. (1) to (2) suffice to describe the effects of a change in the solvency level of the bank.

RAROC is defined as the Division's net profit relative to risk-adjusted capital invested at the beginning of the period (for simplicity of notation, this difference in time is neglected) minus a hurdle rate r imposed by senior management. Net profit consists of two components. The first is net investment income $(\mu - r_D)D$, where μ denotes the rate of return on the capital market and D, deposits. The second is the income $r_G C$ derived from investing solvency capital; here, the rate r_G reflects the fact that these funds must mainly be invested in guilt-edged securities, usually government bonds. Thus,

$$RAROC = \frac{(\mu - r_D(\cdot, S))D + r_G C(\cdot, S)}{C(\cdot, S)} - r.$$

Setting $r = r_G$ for simplicity (although the hurdle rate usually exceeds the rate on government bonds), RAROC can be expressed as a return on risk-adjusted capital (RORAC),

$$RAROC = \frac{(\mu - r_D(\cdot, S))D + r_G C(\cdot, S) - rC(\cdot, S)}{C(\cdot, S)} = \frac{(\mu - r_D(\cdot, S))D}{C(\cdot, S)} = RORAC. \tag{3}$$

Moreover, the volume of the business portfolio and hence D is kept constant during the three (rather short) periods. Then, maximization of RAROC (or RORAC, respectively) in an initial period 0 leads to the following first-order condition for optimal solvency,

$$-\frac{\partial r_D[S^*]}{\partial S} - \frac{\mu - r_D[\cdot, S^*]}{C[\cdot, S^*]} \cdot \frac{\partial C[\cdot, S^*]}{\partial S} = 0, \tag{4}$$

with the bracket notation pointing to the fact that the endogenous determinant S has to be evaluated at its optimal level. Equation (4) can be interpreted as follows. It is optimal for the Division to weigh the favourable marginal effect of increased solvency on the cost of refinancing (first term of the equation, called marginal return of ~~Basel II~~ in terms of risk cost) against its marginal downside effect (second term, called the marginal cost of solvency). The marginal cost of solvency consists of two interacting components. First, solvency ties costly capital C. Secondly however, this cost is particularly high when the rate of return achievable μ exceeds by far the bank's refinancing cost r_D. Note because of $\partial r_D/\partial S < 0$, it must be true that $\mu > r_D$ for an interior solution. solvency

Interestingly, there is evidence suggesting that before the advent of solvency regulation, banks ~~have opted~~ for higher solvency levels than those prescribed even by *Basel III*. Billings and Capie (2007), adjusting for hidden reserves, estimate true capital-asset ratios to have been as high as 8.12 per cent 1959–1967 among the five major UK banks, while *Basel III* mandates a (risk-weighted) common equity-asset ratio of 7 per cent, which is equivalent to a capital-asset ratio of roughly 3.5 per cent. This implies that solvency regulation of the ~~Solvency~~ type may well have the scope of inducing banks to take on more rather than less risk, as will be found in the section 'Summary and Conclusion' later. used to opt Basel

Equation (4) indicates that the optimal adjustment to an exogenous change will not be given once and for all but importantly depends on parameters not yet specified, in particular the risk-return profile inherited from the past. Before substantiating this claim, it is worthwhile to note that regulation fixing a solvency level to be adhered to by all at all times does not only entail disadvantages. One advantage is simplicity, although the Division may be hard put to operationalize 'level of solvency' in all circumstances. Second, a fixed prescribed solvency level in fact makes the cost of (re)financing independent of investment decisions, permitting separation of the bank's lending and borrowing policies, which again results in an important simplification of management tasks. On the downside, uniform regulation creates a similarity in the decision-making situation of regulated firms, which usually results in a type of implicit collusion limiting competition.

Adjustment of Solvency to Exogenous Shocks

During the first period, exogenous shocks impinging on rates of return ($d\bar{\mu}$) and volatility of returns ($d\bar{\sigma}$) occur (see Figure 1 again). To derive the optimal adjustments of the solvency level, the assumptions listed in Table 1 are introduced.

As shown in the appendix, optimal adjustment of the solvency level S^* to a shock $d\bar{\mu} > 0$ in expected returns is given by

$$\operatorname{sgn}\left[\frac{dS^*}{d\bar{\mu}}\right] = \operatorname{sgn}\left[\frac{\partial^2 R}{\partial S \partial\bar{\mu}}\right] = \operatorname{sgn}\left[-\underset{(-)}{\frac{\partial^2 r_D}{\partial S\partial\bar{\mu}}} + \underset{(+)}{\frac{1}{\mu - r_D}}\left(1 - \underset{(+)}{\frac{\partial r_D}{\partial\bar{\mu}}}\right)\underset{(-)}{\frac{\partial r_D}{\partial S}} - \frac{1}{C}\cdot\underset{(-)}{\frac{\partial C}{\partial\bar{\mu}}}\cdot\underset{(-)}{\frac{\partial r_D}{\partial S}} - \underset{(+)}{\frac{\mu - r_D}{C}}\cdot\underset{(-)}{\frac{\partial^2 C}{\partial S\partial\bar{\mu}}}\right]; \quad (5)$$

Table 1. Assumptions of the Model

A1:	$\mu = \bar{\mu} + \hat{\mu}$; $\sigma = \bar{\sigma} + \hat{\sigma}$.	Returns and volatility (μ, σ) are additive in an exogenous ($\bar{\mu}$, $\bar{\sigma}$) component determined on the capital market and an endogenous one.
A2:	$\partial C/\partial\bar{\mu} < 0$.	The higher returns on the capital market, the less risk capital is needed to attain a given solvency level. A positive shock on returns makes positive net values of the bank more likely, therefore reducing the need for risk capital.
A3:	$\partial C/\partial\bar{\sigma} < 0$.	The higher volatility on the capital market, the more risk capital is needed to attain a given solvency level. Positive net values of the bank are less likely, and this must be counteracted by more risk capital.
A4:	$0 < \dfrac{\partial r_D}{\partial\bar{\mu}} < 1$.	The rate of interest paid on deposits reacts to an exogenous increase of returns less than proportionally. Otherwise, the condition $\hat{\mu} > r_D$ for an interior optimum [see Eq. (4) again] would sooner or later be violated.
A5:	$\dfrac{\partial r_D}{\partial\bar{\sigma}} > 0$.	With increased volatility in the market, the bank must offer better conditions to depositors as well.
A6:	$\dfrac{\partial^2 r_D}{\partial S\partial\bar{\mu}} < 0$.	According to A4, the bank must increase its interest rate on deposits when market conditions become more favourable. However, it can afford to adjust to a lesser degree if its solvency level is high.
A7:	$\dfrac{\partial^2 r_D}{\partial S\partial\bar{\sigma}} < \dfrac{\partial^2 r_D}{\partial S\partial\bar{\mu}} < 0$.	According to A5, the bank must follow the market with its interest paid on deposits. However, it can again afford to adjust to a lesser degree if its solvency level is high. The inequality derives from the fact that by A4, $\partial r_D/\partial\bar{\mu}$ is bounded, while $\partial r_D/\partial\bar{\sigma}$ is not.
A8:	$\dfrac{\partial^2 C}{\partial S\partial\bar{\mu}} < 0$.	A higher solvency level calls for more risk capital but to a lesser degree if higher market returns prevail, making positive net values of the bank more likely.
A9:	$\dfrac{\partial^2 C}{\partial S\partial\bar{\sigma}} > 0$.	A higher solvency level calls for more risk capital, especially when market volatility is high, making positive net values less likely.

Source: Author.

the terms are signed using assumptions A2 to A9. Therefore, one obtains

$$\frac{dS^*}{d\bar{\mu}} \begin{cases} < 0 \ \ if \ \ \mu - r_D \to 0; \\ > 0 \ \ if \ \ \mu - r_D \gg 0. \end{cases} \tag{6}$$

These results are intuitive. If the margin $\mu - r_D$ is extremely small [note that the pertinent multiplier $(1 - \partial r_D/\partial\bar{\mu}$ is bounded by (0, 1)], the Division's incentive to preserve costly capital becomes of overriding importance, causing it to reduce its solvency level in response to an exogenous increase in expected returns. However, when the margin becomes larger, less capital is needed to attain a given solvency level. This permits to actually increase the solvency level. Thus, $dS^*/d\bar{\mu} > 0$ is considered the normal response.

Now consider a shock $d\bar{\sigma} > 0$ (again, details are given in the appendix),

$$\operatorname{sgn}\left[\frac{dS^*}{d\bar{\sigma}}\right] = \operatorname{sgn}\left[\frac{\partial^2 R}{\partial S \partial \bar{\sigma}}\right] = \operatorname{sgn}\left[-\underset{(-)}{\frac{\partial^2 r_D}{\partial S \partial \bar{\sigma}}} - \underset{(+)}{\frac{1}{\mu - r_D}} \cdot \underset{(+)}{\frac{\partial r_D}{\partial \bar{\sigma}}} \cdot \underset{(-)}{\frac{\partial r_D}{\partial S}} - \frac{1}{C} \cdot \underset{(+)}{\frac{dC}{d\bar{\sigma}}} \cdot \underset{(-)}{\frac{\partial r_D}{\partial S}} \right.$$

$$\left. - \underset{(+)}{\frac{\mu - r_D}{C}} \cdot \underset{(+)}{\frac{\partial^2 C}{\partial S \partial \bar{\sigma}}}\right]. \tag{7}$$

Using assumptions A2 to A9 once more, one obtains

$$\frac{dS^*}{d\bar{\sigma}} \begin{cases} > 0 & if\ \mu - r_D \text{ small;} \\ < 0 & if\ \mu - r_D \to \infty. \end{cases} \tag{8}$$

Again, the results are intuitive. An exogenous increase in volatility of returns makes refinancing more costly; to counteract this effect, it is appropriate to increase the solvency level if the margin is small. Note that 'small' does not imply 'close to zero' in this case because the relevant term contains $\partial r_D/\partial\bar{\sigma}$ and $\partial r_D/\partial S$, which are both first-order. Thus, $dS^*/d\bar{\sigma} > 0$ can be regarded as the normal response. Yet, in the presence of very high margins, the opportunity cost of increased solvency becomes excessive, motivating a decrease in solvency.

Determination of the Endogenous Efficiency Frontier

In the third period, the bank inherits a net adjustment of solvency dS^* from the second period that is the result of responses to the shocks $(d\bar{\mu}, d\bar{\sigma})$ that occurred in the first period. The Division now proceeds to adjust the endogenous components $\hat{\mu}$ and $\hat{\sigma}$. Performing comparative statics 'in reverse', optimal adjustments can be predicted using Eqs. (5) and (7), respectively, with dS^* now assuming the role of an exogenous shock. By reshuffling the bank's assets, the Division therefore effects changes $d\hat{\mu}$ and $d\hat{\sigma}$, creating an endogenous efficiency frontier with slope $d\hat{\mu}/d\hat{\sigma}$, on which senior management will proceed to choose the optimum (see Section V.1). This slope can be obtained by dividing Equation (7) by Equation (5), yielding

d on same line 2x

$$\left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_{S^*} = \frac{-\overset{(-)}{\dfrac{\partial^2 r_D}{\partial S \partial \bar{\sigma}}} - \overset{(+)}{\dfrac{1}{\mu - r_D}} \cdot \overset{(+)}{\dfrac{\partial r_D}{\partial \bar{\sigma}}} \cdot \overset{(-)}{\dfrac{\partial r_D}{\partial S}} - \dfrac{1}{C} \cdot \overset{(+)}{\dfrac{\partial C}{\partial \bar{\sigma}}} \cdot \overset{(-)}{\dfrac{\partial r_D}{\partial S}} - \overset{(+)}{\dfrac{\mu - r_D}{C}} \cdot \overset{(+)}{\dfrac{\partial^2 C}{\partial S \partial \bar{\sigma}}}}{-\underset{(-)}{\dfrac{\partial^2 r_D}{\partial S \partial \bar{\mu}}} + \underset{(+)}{\dfrac{1}{\mu - r_D}} \left(1 - \underset{(+)}{\dfrac{\partial r_D}{\partial \bar{\mu}}}\right) \underset{(-)}{\dfrac{\partial r_D}{\partial S}} - \dfrac{1}{C} \cdot \underset{(-)}{\dfrac{\partial C}{\partial \bar{\mu}}} \cdot \underset{(-)}{\dfrac{\partial r_D}{\partial S}} - \underset{(+)}{\dfrac{\mu - r_D}{C}} \cdot \underset{(-)}{\dfrac{\partial^2 C}{\partial S \partial \bar{\mu}}}}. \tag{9}$$

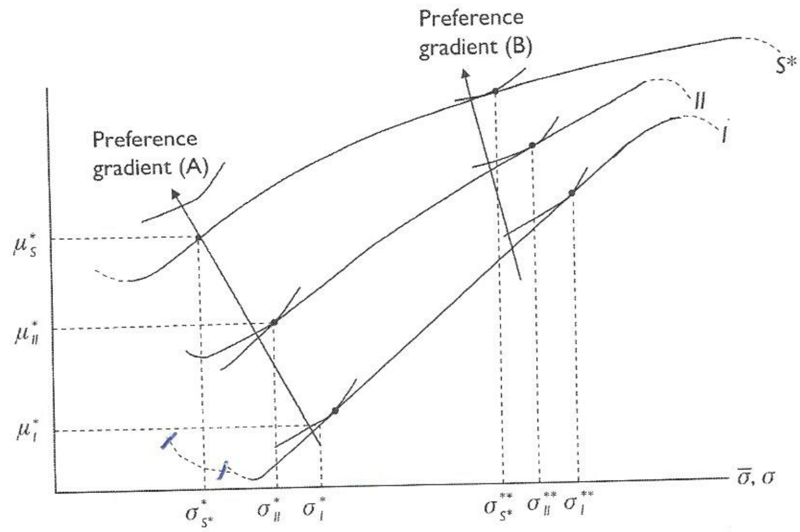


Figure 2. Endogenous Efficiency Frontiers in (μ,σ)-space.

Source: Author.

] if possible Figure 2 explicitly prepared for MIC attached

The sign of Eq. (9) is negative both if $(\mu - r_D) \rightarrow 0$ and if $(\mu - r_D) \rightarrow \infty$ in view of Eqs. (6) and (8). In Figure 2, these extreme cases are shown for completeness. However, with $dS^*/d\bar{\mu} > 0$ and $dS^*/d\bar{\sigma}$ constituting the normal responses [see the discussion below Eqs. (6) and (8)], the slope of the endogenous efficiency frontier is positive for intermediate values of $(\mu - r_D)$ and hence μ by assumptions A1 and A4. Moreover, a negatively sloped internally perceived efficiency frontier in (μ,σ)-space would contradict daily experience on capital markets $(d\mu/d\sigma > 0)$. A crucial result is that the slope defined in Eq. (9) depends not only on observable parameters such as (μ, r_D) and first-order effects the regulator likely is aware of such as $(\partial C/\partial\bar{\mu}, \partial C/\partial\bar{\sigma}, \partial r_D/\partial S)$ but also terms such as $\partial^2 C/\partial S\partial\bar{\mu}$ and $\partial^2 C/\partial S\partial\bar{\sigma}$, which indicate that the relationship between required risk capital and solvency depends on conditions on the capital market (see assumptions A8 and A9 again).

Figure 2 shows three endogenous efficiency frontiers. Note that μ and $\bar{\mu}$ as well as σ and $\bar{\sigma}$ are depicted on the same axis, reflecting the assumption that, for example, a low first-period value of $\bar{\sigma}$ tends to translate into a low third-period. The first frontier (labelled S^*) holds prior to the influence of regulation. The two other frontiers (labelled *I* and *II*, respectively) are modified by *Basel I* and *Basel II* regulation in ways to be discussed in the section 'Summary and Conclusion' later.

Conclusion 1: Due to its responses to shocks in expected rate of return and volatility in the process of sequential adjustment, the Division induces an endogenous efficient frontier, whose slope also depends on the changing relationship between risk capital and solvency.

There is some historical evidence supporting this conclusion. After adjusting for hidden reserves, Billings and Capie (2007) find that capital-asset ratios of the five major UK banks were particularly high during 1942–1946, when they had to finance the war effort. Their explanation is '…that much of their lending to government was in the form of marketable securities, which have generated *exposure to fluctuations in market prices*' (p. 152, emphasis added). Banks apparently realized that their efficiency frontiers depended on changes in the relationship between solvency and risk capital due to changing market conditions during World War II.

Effects of Solvency Regulation on the Efficiency Frontier

The objectives of solvency regulation differ from those of the bank, who by assumption seeks to be on the efficient (μ, σ)-frontier as given in Eq. (9) and depicted as $d\mu/d\sigma|_{S^*}$ in Figure 2. Solvency regulation is designed to avoid the external costs caused by insolvencies described in the section 'Adjustment of Solvency to Exogenous Shocks'. Its main instrument is capital requirements, based on the norms of the Solvency Committee on Banking Supervision, an agency of the Bank for International Settlements.

Basel I

Basel I stipulates capital requirements as a function of risk-weighted assets and separately for off-balance sheet positions (Solvency Committee on Banking Supervision, 1988). Its focus is on the relationship between solvency and capital. By defining four asset classes with fixed weights, *Basel I* imposes a fixed relationship between solvency capital C and solvency S (see the locus B of Figure 3). It therefore does not allow banks to react to changes in market conditions affecting the risk characteristic of assets. In terms of the model, this neglect amounts to the restrictions

$$\frac{\partial^2 C}{\partial S \partial \overline{\mu}} = 0, \quad \frac{\partial^2 C}{\partial S \partial \overline{\sigma}} = 0. \tag{10}$$

Inserting this in Eq. (9), one immediately sees that the numerator increases while the denominator increases. One therefore obtains for the slope of the efficiency frontier (subscript I denoting *Basel I*),

$$\left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_I => \left.\frac{d\overline{\mu}}{dS^*}\right|_{S^*} \tag{11}$$

The *Basel I* frontier therefore runs steeper than the original S^* frontier, approaching but never crossing it for high values of μ because regulation cannot increase the bank's feasible set. Of course, there are other influences that may affect the slope of the efficiency frontier, such as changes in inflationary expectations. However, these are related to the business cycle whereas the 'deformation' caused by *Basel*-type regulation is structural.

One might argue that the bank can choose to act in accordance with parameters it knows to be of importance, contrary to the regulator's decision rule. This amounts to neglecting the restrictions stated in Equation (10). However, as emphasized by Power (2004, ch. 7), managers are responsibility-averse, leading them to use regulatory decision rules as a convenient justification of their own actions. For example, let there be a second-period upward adjustment in ~~Basel~~ indicating ↔ solvency
that the bank should move away from the origin on the efficiency frontier. With the flat endogenous efficiency frontier S^* auf Figure 1 in view, the Division would propose to accept a substantial increase in volatility whereas based on the steeper efficiency frontier induced by *Basel I*, the suggested increase is smaller. If the bank's senior management were to move along S^*, it could be criticized by the regulator for taking on an excessive amount of risk. This threat causes a responsibility-averse management to adopt the restrictions of Equation (10) and view the steeper *Basel I* efficiency frontier as the relevant one.

For predicting optimal solutions, one needs two assumptions regarding the preferences of bank's senior management. The first is the assumption of risk aversion on the part of senior management. In principle, fully diversified owners would like management to accept a great deal of risk because this allows them to benefit from an increase in the value of their shares [which have properties of a call option, see, e.g., Zweifel and Eisen (2012), ch. 4.3]. Managers, however, being less than perfectly diversified with their human capital tied to the employing firm, have reason to be risk-averse. Given imperfect governance by (dispersed) ownership, management can follow its preferences at least to some extent (Shrieves and Dahl, 1992). Second, homotheticity of risk preferences is imposed in order to obtain sharper predictions. However, homotheticity also implies stability because the indifference curves retain their shape regardless of the bank's position in (μ,σ)-space whereas, for example, 'irrational exuberance' (Shiller, 2005) can be interpreted as reflecting reduced risk aversion in a boom phase but increased risk aversion in a downturn. Therefore, homotheticity may be a more questionable assumption in this context than in other domains of microeconomic theory.

Under these assumptions, *Basel I* regulation induces the bank to be less conservative regardless of degree of risk aversion (type A or B in Figure 2; see the movements from $\sigma^*_{S^*}$ to σ^*_I and from $\sigma^{**}_{S^*}$ to σ^{**}_I, respectively).

Conclusion 2: Regulation of the *Basel I* type is predicted to induce banks to take a more risky position than they would on their own, running counter stated objectives of solvency regulation.

One could argue that according to Figure 1, this increase in volatility goes along with an increase in expected returns; therefore, solvency as defined by VaR or EVaR need not diminish. Using the lognormal distribution of returns as an approximation, an increase of σ by x per cent would have to be associated with an increase in μ by x per cent for VaR and EVaR to remain constant, implying unitary elasticity [in analogy to Cummins and Nye (1981)]. In Figure 1, the corresponding locus is a straight line through the origin with a 45 degree slope. However, much lower slopes (typically below 0.5) have been found in empirical research [see, e.g., Woehrmann et al. (2004)]. Therefore, the predicted increase in σ indeed causes a reduction in solvency.

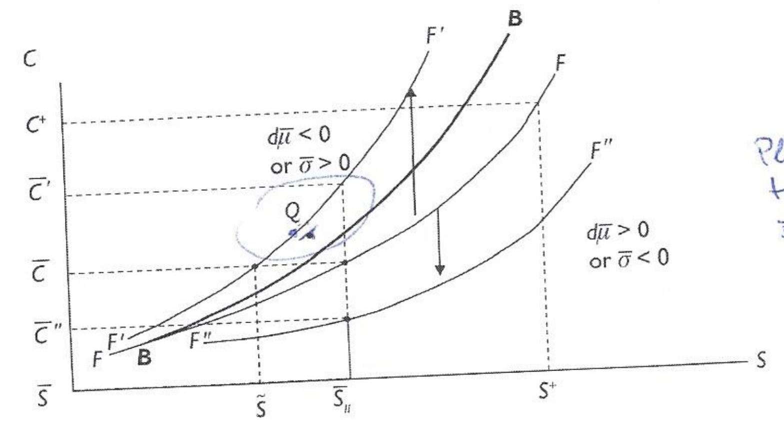
Note that this prediction holds even if the regulation-induced downward shift of the efficiency frontier is minimal. The crucial point is that *Basel I* signals to banks that interaction parameters their investment divisions would take into account can be neglected, causing their perceived efficiency frontier to indicate that more return can be achieved on expectation for accepting a given increment in volatility. As an example, consider a bank heavily engaged in the financing of mortgages. When expected rates of return in the capital market increase ($d\bar{\mu} > 0$), it can free risk capital (decreasing its effective solvency level somewhat and paying a higher rate of interest on deposits) in favour of an investment in a more risky asset without violating the *Basel I* norm. The consequence of this regulation-induced effect is pointed out by Benink and Benston (2005), 'Although the CEOs and directors of banks may not deliberately hold an insufficiently high level of capital necessary to avoid insolvency, they may be lulled into believing that they are adequately capitalized if they adhere to the Solvency Committee's models (which they are unlikely to understand' (p. 308).

Finally, it is telling that both the International Monetary Fund (IMF) and the European Central Bank (ECB) are engaged in stress testing of banks, simulating the type of exogenous shocks analyzed in this article. Specifically, Box 2 of IMF Country Report No. 13/68 states, 'Higher cost of funding in the baseline and adverse scenarios could arise due to: higher short- and long-term interest rates, increased banks' spreads (which depended just on a bank's sovereign's spreads), collateral value declines, and more expensive deposits' (IMF, 2013). The report also states that existing regulation (of the *Basel* type) has been neglecting these shocks originating in capital markets. Evidently, both the IMF and the ECB are concerned that banks may have been exposed to excessive risk in spite of (possibly because of, as argued here) current *Basel*-type solvency regulation.

Basel II

Basel II allows a choice of approach for the calculation of capital requirements, namely, the standardized approach and the internal-ratings-based approach (Solvency Committee on Banking Supervision, 2004). While the first approach is based on *Basel I*, the second lets banks choose their probability of default, their percentage loss at default, and the maturity of their credits. Large institutions with average and below-average credit risks mostly prefer the internal-ratings-based approach to save on capital despite its higher cost of implementation. In terms of the model, *Basel II* permits these banks to take all elements of Eq. (9) into account which amounts to a lifting of the restrictions of Eq. (10) as long as the constraint regarding the solvency level is not binding.

To show this, assume that the bank has opted for the more flexible internal-ratings-based approach. Taken together, the rules promulgated by the Solvency Committee on Banking Supervision (2004, especially para 40 to 44) establish a relationship between a targeted solvency level and required risk capital.



Plse move point to FF' line

Fig. 3 attached

Figure 3. Implications of *Basel II* Regulation

Source: Authors.

This relationship (which the bank cannot modify once it has selected its internal model) is depicted by the locus labelled F in Figure 3. It has increasing slope to reflect decreasing marginal returns to risk capital as stated in Equation (2). Locus F runs below locus B of *Basel I*, reflecting that *Basel II* permits banks to save on risk capital. The other difference is that *Basel II* imposes a minimum degree of solvency, which is denoted by $\bar{S}_{II}$.

Now let a shock $d\bar{\sigma} > 0$ occur (volatility of returns has increased). In keeping with assumption A9, this corresponds to a steepening of the locus, resulting in F' from the bank's point of view. It indicates that a given capital $\bar{C}$ would now only suffice to guarantee a solvency level $\tilde{S} < \bar{S}_{II}$. Therefore, in order to keep to the *Basel II* norm, a bank that just satisfied it initially would have to come up with the full additional amount of capital $(\bar{C}' - \bar{C})$. In the absence of *Basel II*, the bank would opt for a point such as Q that entails a somewhat lower solvency level (compared to $\bar{S}_{II}$) in return for a substantial saving of costly risk capital. A bank with excess solvency, symbolized by the combination (S^+, C^+), would not have to react to the shock $d\bar{\sigma} > 0$. The same conditional responses are predicted for a shock $d\bar{\mu} < 0$, that is, a drop in the mean return on investments. up to line

Conversely, consider a shock $d\bar{\sigma} < 0$, that is, capital markets have become less volatile. For the bank, this causes the locus F of Figure 2 to become flatter, such as F''. Now $\bar{C}'' < \bar{C}$ suffices to reach the prescribed solvency level, and the 'marginal' bank that was at $\bar{S}_{II}$ initially can reduce capital by as much as $(\bar{C}'' < \bar{C})$. This of course holds true of $d\bar{\mu} > 0$ as well.

In sum, one has the following set of conditional predictions (in absolute value) for *Basel II*, focusing on the critical changes $d\bar{\mu} < 0$ and $d\bar{\sigma} > 0$,

$$0_I < \left|\frac{\partial^2 C}{\partial S \partial \bar{\mu}}\right|_{II} < \left.\frac{\partial^2 C}{\partial S \partial \bar{\mu}}\right|_{S^*} \quad \text{if} \quad d\bar{\mu} < 0 \text{ and } S = \bar{S}_{II}; \qquad 7;$$

$$\cancel{\text{if}} \quad 0_I < \left|\frac{\partial^2 C}{\partial S \partial \bar{\sigma}}\right|_{II} < \left.\frac{\partial^2 C}{\partial S \partial \bar{\sigma}}\right|_{S^*} \text{if} \quad d\bar{\sigma} > 0 \text{ and } S = \bar{S}_{II}. \qquad (12)$$

See submitted text

Here, 0_I symbolizes the zero restriction imposed by *Basel I* [see Eq. (10) again]. Applied to Eq. (9) and in view of assumptions A8 and A9, these restrictions again cause the numerator to increase and the numerator, to decrease. One therefore obtains,

$$\left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_{II} > \left.\frac{d\hat{\mu}}{d\hat{\sigma}}\right|_{S*} \quad \text{if } d\overline{\sigma} > 0 \text{ or } d\overline{\mu} < 0 \text{ and } S = \overline{S}_{II}. \tag{13}$$

Figure 2 illustrates once more. *Basel II* being less stringent (at least by intent), the frontier runs higher than that of *Basel I* but still lower than absent regulation. To make up for reduced expected returns, even a strongly risk-averse senior management (preferences of type A) is predicted to opt for a more risky allocation ($\sigma^*_{II} > \sigma^*_{S*}$) provided the bank just satisfied the *Basel II* norm initially. This condition presumably holds as a rule for those banks with a less risk-averse management (preferences of type B), again resulting in an investment policy that entails a higher volatility of returns than without regulation. In comparison with *Basel I*, these counter-productive effects are less pronounced, since *Basel II* causes a smaller downward shift of the efficiency frontier (see Figure 2 again). Note that this argument holds *ceteris paribus*, abstracting from stated intentions to use the transition from *Basel I* to *Basel II* for getting banks to increase their level of solvency.

In sum, *Basel I* and *Basel II* are predicted to have similar effects in one respect. Both may induce banks to opt for a more rather than less risky exposure than if they were optimizing free of the respective restraints. However, the two regulations differ in another respect. *Basel I* causes a 'deformation' of the (μ, σ)-frontier for all banks. By way of contrast, the 'deformation effect' of *Basel II* is limited to the subset of banks that just satisfied the norm initially.

Conclusion 3: *Basel II* is predicted to induce banks just compliant with the norm to pursue a riskier investment policy than absent regulation, but less so than under *Basel I*, again causing a reduction in solvency.

Basel III

The details of implementation of *Basel III* regulation are not known yet at the time of writing. However, its objective clearly is to prescribe a higher level of solvency, to be attained by more solvency capital of which a greater part is to be equity (Bank for International Settlements, 2011; Solvency Committee on Banking Supervision, 2011). In terms of Figure 3, the mandated solvency level shifts towards S^+ or even beyond. The consequence of this shift is that the set of banks that does not have to react to a shock $d\overline{\sigma} > 0$ shrinks while the set of banks that have to come up with the full additional amount of capital to meet *Basel III* requirements increases (see the discussion in ~~Section 6.2~~ again). A first indication of this effect is the case of Credit Suisse, a Swiss bank: 'The capital required for Credit Suisse's fixed income business is believed to have trebled under *Basel III* rules, forcing it to revamp its trading strategy' (*Financial Times*, of June 9, 2014).

→ the preceding section

Therefore, the steepening of the efficiency frontier predicted in Eq. (13) applies to a larger subset of banks, at least during a (lengthy) time of transition that sees banks struggling to increase their equity and reserves. Moreover, the fact that an increased share of solvency capital must be equity means an increase in regulatory stringency, causing the endogenous efficiency frontier pertaining to *Basel III* to be shifted back down towards that of *Basel I* (see Figure 2 again). ~~Indeed, the *Financial Times* (June 9, 2014) wrote, 'The capital required for Credit Suisse's fixed income business is believed to have trebled under *Basel III* rules, forcing it to revamp its trading strategy'.~~ Conclusion 3 therefore is predicted to hold more generally, implying that more banks may in fact be induced to pursue a riskier investment policy than in the absence of regulation.

duplication, sorry

Summary and Conclusion

The basic hypothesis of this article states that banks' investment divisions seek to attain a solvency level that balances the advantage of lower refinancing cost against the disadvantage of tying capital that would yield higher returns in other uses. However, this solvency level is too low from a societal point of view because it neglects the fact that insolvency causes substantial external costs. In a simple model of bank behaviour, the investment division maximizes the risk-adjusted rate of return on (risk-adjusted) capital (RAROC). A higher level of solvency (defined in terms of VaR or EVaR, respectively) lowers the cost of refinancing but causes returns forgone by tying extra capital. The division learns the slope of its efficiency frontier in (μ,σ)-space in the course of three periods. In period 1, exogenous changes in expected returns and in the volatility of returns on the capital market occur. These changes induce adjustments during period 2, predicted by comparative static analysis. In period 3, previous adjustment acts like an exogenous change, triggering a reallocation of assets and liabilities. These adjustments, derived from 'reverse comparative statics', define the slope of a perceived endogenous frontier in (μ, σ)-space prior to solvency regulation.

However, this slope depends importantly on the fact that the relationship between risk capital and *Basel I* is not stable but depends on exogenous changes in expected returns and volatility occurring in the capital market (Conclusion 1). The regulations imposed by *Basel I* are now shown to neglect this dependence on market conditions, causing a modification of the risk-return frontier as perceived by the regulated bank. This modification may well induce senior management to take a more risky position than it would absent regulation (Conclusion 2). Although this increase in risk goes along with an increase in expected returns, it entails a lower degree of solvency. The implications of *Basel II* are more complex. Still, banks initially just attaining the prescribed solvency level are again predicted to react to regulation by taking a more risky position than they would have otherwise (Conclusion 3). As to *Basel III*, its likely effect will be to increase the subset of banks responding in the same way, running counter the very objective of the regulators, who want banks take on less rather than more risk.

All of these predicted adjustments may be considered to amount to regulatory failure. However, it would be inappropriate to conclude that *Basel I*, *II* or *III* or even solvency regulation in general should be revoked. First, the model analyzed in this article might be too simplistic; banks possibly pursue other objectives than just maximizing RAROC (or RORAC, respectively). Second, the (μ, σ)-approach adopted in this article is compatible with equilibrium in the capital market only if expectations are homogenous and quoted prices are available for all assets. Third, *Basel II* already constitutes an improvement over *Basel I* in that its self-defeating effect is limited to the (usually small) subset of banks that initially had just been compliant with the prescribed solvency level. As to *Basel III*, the short-run increase in this problematic subset effect has to be weighed against the long-run increase in solvency levels generally achieved. And finally, assuming that current solvency regulation does entail more benefit than cost, one would have to find an alternative whose benefit-cost ratio beats that of the *Solvency* type (for reform proposals, see, e.g., Benink and Benston, 2005: 311–321).

Yet, the following insights are likely to be robust. Solvency regulation of the *Basel* type is commonly justified by the need to strengthen banks' ability to bear losses thanks to additional capital of 'good quality' permitting them to continue their activity. Although bank's required capital buffer is geared to their risk-weighted assets, the analysis performed in this article shows that even *Basel III* may fail to enhance banks' ability to bear losses. The reason is that it too does not take account of shocks originating in the capital market which modify the relationship between solvency capital and the degree of solvency achieved (see Figure 3 again). Indeed, the increased capital requirements of *Basel III* run the risk of weakening rather than strengthening the loss-bearing capacity of banks that were compliant with regulation before the shock. This risk characterizes a lengthy period of adjustment to the new rules (consider again the case of Credit Suisse cited ~~at~~ the end of the preceding section).

toward

Moreover, the two parameters appearing in Eq. (10) makes clear that the extent to which shocks from the capital market modify the relationship between solvency capital and solvency depends on the bank's clientele. A bank whose customers highly value an increase in its solvency level when expected returns on the capital market fall or volatility shoots up is heavily affected, while a bank with less 'nervous' customers is sheltered from these shocks.

In sum, the solvency criteria applied by *Basel*-type regulation are too coarse to be able to reflect a bank's specific situation adequately. Efficient solvency regulation would have to closely reflect the objectives and constraints governing banking behaviour rather than pursue a 'one size fits all' philosophy. This philosophy proves to be inappropriate also when comparing the effects of solvency regulation of banks and insurers (see Zweifel, 2014), calling for further research hopefully resulting in an improved tailoring of solvency regulation to the specifics of both financial institutions.

Appendix

First, consider a shock $d\bar{\mu}$ disturbing the first-order condition Eq. (4). With R shorthand for RAROC, the comparative static equation reads,

$$\frac{\partial^2 R}{\partial S^2} dS^* + \frac{\partial^2 R}{\partial S \partial \bar{\mu}} d\bar{\mu} = 0. \tag{A.1}$$

Since $\partial^2 R/\partial S^2 < 0$ in the neighbourhood of a maximum, sgn $[\partial^2 R/\partial S \partial \bar{\mu}]$ determines sgn $[dS^*/d\bar{\mu}]$. Differentiating Eq. (4) w.r.t. $\bar{\mu}$, one has

$$\frac{\partial^2 R}{\partial S \partial \bar{\mu}} = -\frac{\partial^2 r_D}{\partial S \partial \bar{\mu}} - \left(\left(1 - \frac{\partial r_D}{\partial \bar{\mu}}\right) C - (\mu - r_D) \frac{\partial C}{\partial \bar{\mu}}\right) \frac{1}{C^2} \cdot \frac{\partial C}{\partial S} - \frac{\mu - r_D}{C} \cdot \frac{\partial^2 C}{\partial S \partial \bar{\mu}}. \tag{A.2}$$

Using Eq. (4) to obtain $\partial C/\partial S = -(\mu - r_D)^{-1} (\partial r_D/\partial S) \cdot C$, one has

$$\begin{aligned} \frac{\partial^2 R}{\partial S \partial \bar{\mu}} = & -\frac{\partial^2 r_D}{\partial S \partial \bar{\mu}} + \left(1 - \frac{\partial r_D}{\partial \bar{\mu}}\right) \frac{1}{C} \cdot \frac{1}{\bar{\mu} - r_D} \cdot C \cdot \frac{\partial r_D}{\partial S} - (\mu - r_D) \frac{\partial C}{\partial \bar{\mu}} \cdot \frac{1}{C^2} \cdot \frac{1}{\mu - r_D} \cdot C \cdot \frac{\partial r_D}{\partial S} \\ & - \frac{\mu - r_D}{C} \cdot \frac{\partial^2 C}{\partial S \partial \bar{\mu}}. \end{aligned} \tag{A.3}$$

This can be simplified to become Eq. (5) of the text.

Now consider $d\bar{\sigma} > 0$. In full analogy to (A.1), one obtains from Eq. (4),

$$\left[\frac{\partial^2 R}{\partial S \partial \bar{\sigma}}\right] = -\frac{\partial^2 r_D}{\partial S \partial \bar{\sigma}} - \left(-\frac{\partial r_D}{\partial \bar{\sigma}} \cdot C - (\mu - r_D) \cdot \frac{\partial C}{\partial \bar{\sigma}}\right) \cdot \frac{1}{C^2} \cdot \frac{\partial C}{\partial S} - \frac{\mu - r_D}{C} \cdot \frac{\partial^2 C}{\partial S \partial \bar{\sigma}}. \tag{A.4}$$

Using Equation (4) again to substitute $\partial C/\partial D$, one has

$$\begin{aligned} \frac{\partial^2 R}{\partial S \partial \bar{\sigma}} = & -\frac{\partial^2 r_D}{\partial S \partial \bar{\sigma}} - \frac{\partial r_D}{\partial \bar{\sigma}} \cdot \frac{1}{C} \cdot \frac{1}{\mu - r_D} \cdot C \cdot \frac{\partial r_D}{\partial S} - (\mu - r_D) \frac{\partial C}{\partial \bar{\sigma}} \cdot \frac{1}{C^2} \cdot \frac{1}{\mu - r_D} \cdot C \cdot \frac{\partial r_D}{\partial S} \\ & - \frac{\mu - r_D}{C} \cdot \frac{\partial^2 C}{\partial S \partial \bar{\sigma}}. \end{aligned} \tag{A.5}$$

Slight rearrangement yields Equation (7) of the text.

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